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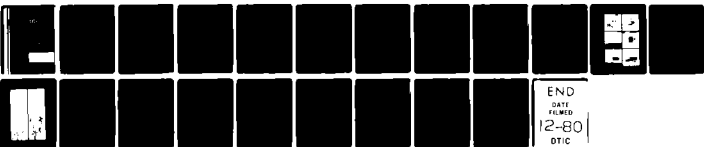   IMAGE ENHANCEMENT BY SPECTRAL RATIOING, (U)
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IMAGE ENHANCEMENT BY SPECTRAL RATIOING

J.F. Boulter

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Centre de Recherches pour la Défense

Defence Research Establishment

Valcartier, Québec

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IMAGE ENHANCEMENT BY SPECTRAL RATIOING

by

J. F. Boulter

CENTRE DE RECHERCHES POUR LA DEFENSE

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RESUME

Dans une image produite par la réflexion de la radiation, le contraste résultant des différents types de surface est souvent plus important que celui causé par des différences de l'illumination ou de l'orientation des surfaces. Ce contraste peut être difficile à prévoir, en pratique. On démontre que, dans plusieurs cas, le contraste produit par les différences de l'illumination ou de l'orientation peut être réduit ou éliminé si on divise une image obtenue dans une bande spectrale par celle provenant d'une bande spectrale différente. On applique cette technique pour rehausser des images des véhicules militaires enregistrées sur un film en couleur de même que celles d'objets faits par l'homme par rapport à la végétation sur une image obtenue avec balayeur multispectral. (NC)

ABSTRACT

In a reflectivity image, contrast produced by differences in surface material is often of more interest than that produced by differences in surface orientation or illumination. The latter factors may be difficult to predict or to allow for in practice. We show that, in certain cases, contrast caused by differences in surface orientation and illumination may be reduced or eliminated by dividing an image obtained in one spectral band by one obtained in a different spectral band. We illustrate this technique by enhancing the images of military vehicles recorded on color film, and by enhancing man-made objects in an aerial multispectral scanner image relative to vegetation. (U)

TABLE OF CONTENTS

1.0 INTRODUCTION

Contrast in an image formed with radiation reflected from an area containing a target of interest depends on the orientation, reflectivity and illumination of the surfaces in the target and background regions. In some cases, contrast due to differences in surface material is more important than that due to differences in orientation or illumination. The latter factors may be difficult to predict or to allow for in practice, and the contrast that they produce may have undesired effects. Glint or shadowed regions can reduce the performance of an automatic target acquisition or tracking system, for example. In this report we describe a method, which can be applied in certain cases, for enhancing the contrast due to differences in surface material and for reducing that due to the orientation or illumination of the reflecting surfaces.

The method requires 2 registered images of the target area obtained over different spectral ranges. Under certain assumptions, the ratio of the 2 images is independent of the orientation and the illumination of the surfaces, and depends only on their spectral reflectivities. Ideally, all contrast in the ratio image will be due only to differences in surface material.

In Sect. 2.0, we describe the theory of the processing and briefly discuss how the spectral responses of the 2 detectors should be chosen to maintain or to improve the overall contrast of the target against its background while the orientation and illumination effects are reduced. In Sect. 3.0, we use the technique to enhance the images of targets consisting of military vehicles against backgrounds of

foliage and ground terrain, and to enhance man-made structures in aerial imagery relative to vegetation. Some possible applications of the technique for improving images intended for subsequent human or machine analysis are given in Sect. 4.0.

This work was performed at DREV during the period February-May 1979 under PCN 21J03, Imaging Seekers and PCN 21J07, Target Acquisition.

2.0 THEORY

Consider a ray of illumination reflected from a target into the field of view of a point detector. The direction of the incident ray is specified by the 2-component vector $\bar{\alpha}$ and that of the reflected ray by the 2-component vector $\bar{\beta}$. The shape of the target is described by the normal to its surface $N(\bar{\beta})$, and its surface reflectivity by the function $R(\lambda,\bar{\theta},\bar{\phi})$. The 2-component vectors $\bar{\theta}$ and $\bar{\phi}$ represent the angles between the normal to the target surface and the directions of the incident and the reflected rays. Figure 1 illustrates the projection of this geometry onto a plane that passes through the point of reflection on the target.

We assume that the illumination function $I(\lambda,\bar{\alpha})$ is the same for all points on the target and that it depends only on the wavelength and on the direction of incidence. Consider a small area on the target that corresponds to the incremental solid angle $d\beta$ that is within the field of view of a linear detector. This area receives illumination within a solid angle $d\alpha$ and a spectral range $d\lambda$. The corresponding detector output dW is proportional to the product of the illuminance, the surface reflectivity and the spectral response of the detector $D(\lambda)$:
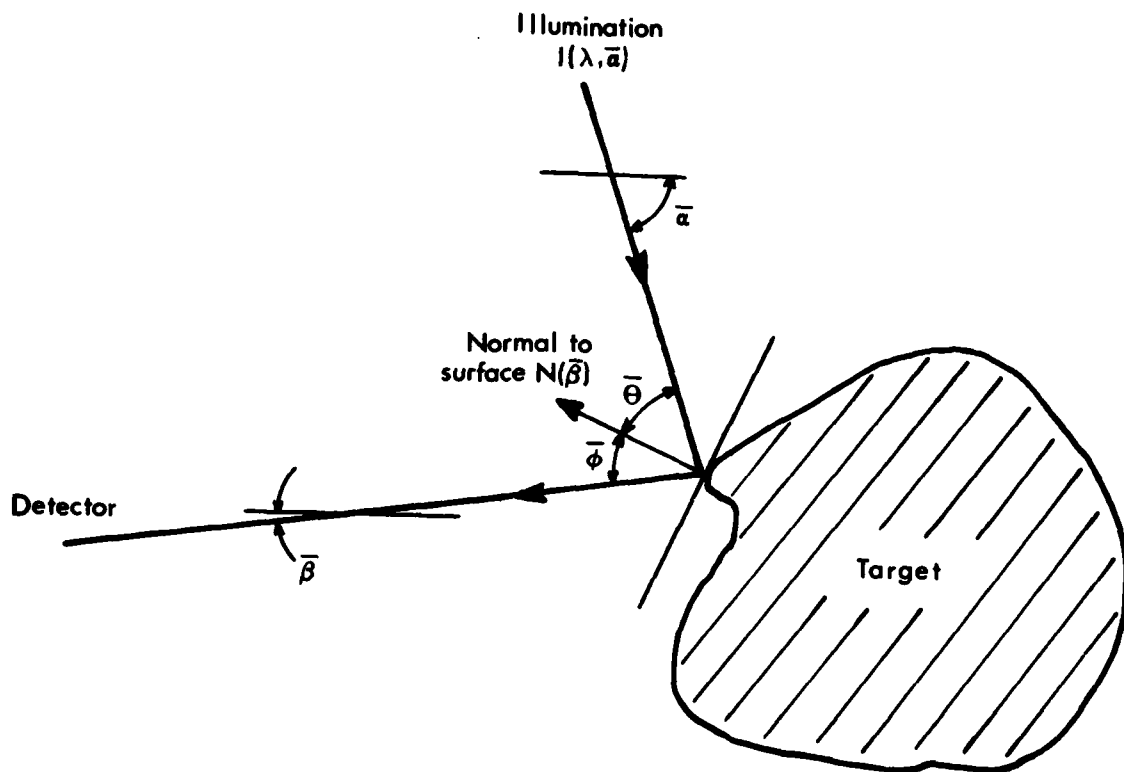
FIGURE 1 - Assumed model for the image formation process

$$dW(\lambda,\bar{\alpha},\bar{\beta}) = I(\lambda,\bar{\alpha}) \ R(\lambda,\bar{\theta},\bar{\phi}) \ D(\lambda) \ d\alpha \ d\beta \ d\lambda \qquad [1]$$

We make 2 assumptions that will be more or less true in practice. The first one is that the reflectivity R can be written as the product of a part that depends only on wavelength, $R_1(\lambda)$, and a part that depends only on the angles of incidence and reflectance, $R_2(\bar{\theta},\bar{\phi})$. The second one is that the illumination I can be written as the product of a constant I_0, a part that depends only on the wavelength, $I_1(\lambda)$, and a part that depends only on the illumination direction, $I_2(\bar{\alpha})$.

We obtain the total detector output W by integrating eq. 1 over all illumination directions A, over the detector field of view B and over all wavelengths . The assumed separability of the illumination and reflectivity functions permits the wavelength and spatial integrations to be performed independently of one another:

$$W = I_0 \int_0^\infty I_1(\lambda) \ R_1(\lambda) \ D(\lambda) \ d\lambda \iint_{A \ B} I_2(\bar{\alpha}) \ R_2(\bar{\theta},\bar{\phi}) \ d\alpha \ d\beta \qquad [2]$$

Suppose 2 coincident detectors with different spectral responses D_i and D_j form registered images of the same target area. At all points in the 2 images, the ratio of the detector responses:

$$\frac{W_i}{W_j} = \frac{\int_0^\infty I_1(\lambda) \ R_1(\lambda) \ D_i(\lambda) \ d\lambda}{\int_0^\infty I_1(\lambda) \ R_1(\lambda) \ D_j(\lambda) \ d\lambda} \qquad [3]$$

depends only on the integrals over wavelength – the spatial integrals are the same for both detectors and cancel in the ratio. The ratio is

independent of the absolute illumination level I_0, the angular distribution of the illumination I_2, the angular reflectivity function of the surface R_2, and of the orientation or irregularities in the surface. For a given pair of detectors D_i and D_j, and for illuminance with spectral content I_1, the ratio depends only on the spectral reflectivity of the surface R_1. Contrast in the ratio image depends only on differences in the spectral reflectivies of the surfaces, and not on their orientations or illuminances.

The spectral responses of the 2 detectors must be chosen so as to ensure that the target of interest has sufficient contrast against its background in the ratio image. It is possible for the ratio given by eq. 3 to have the same value for a background region as for a target region with an entirely different surface; in such a case, the target has no contrast against its background. The choices for the detector responses D_i and D_j that optimize the tradeoff between target-background contrast and signal-to-noise ratio must take account of the noise levels present on each detector output as a function of wavelength as well as the distributions of I_1 and R_1. In performing this optimization, the overall detector spectral responses used in eq. 3 can be synthesized by combining the outputs of several detectors with different spectral responses.

The physical model represented by eq. 1, and the assumed separability of the illumination and reflection processes into wavelength dependent and wavelength independent parts, is only approximately valid in practice. For example, if the target is illuminated by multiple sources with different spectral contents (e.g.

directly by the sun as well as indirectly by the light reflected from a nearby "colored" surface), then the illumination cannot be expressed as the product of independent parts. Also, particularly for highly specular surfaces, the angular reflectivity R_2 may depend significantly on wavelength, or the spectral reflectivity R_1, on the angles of incidence and reflectance (Ref. 1). Furthermore, if either detector is not linear, the ratio may not be independent of surface orientation and illumination. However, as shown in Sect. 3.0, in some situations of practical interest, the assumptions are sufficiently true to allow useful target enhancement based on this principle.

3.0 TARGET ENHANCEMENT EXAMPLES

Color images of a helicopter and of the front and side views of a canvas-back truck were recorded on Kodachrome-64 color transparency film. Regions of the images were digitized to 256- by 256-element resolution with a high quality vidicon camera interfaced to an interactive digital image-processing system (Ref. 2). This vidicon is linear within 2% over a 3-decade dynamic range. Each image was digitized 4 times: first without a color filter and then with 3 Kodak color filters (types 25 red, 58 green and 47 blue) inserted individually between the camera and the transparency. Figures 2(a), (c) and (e) show the original digitized images obtained without a color filter whereas Figs. 2(b), (d) and (f) show the ratios of 2 images obtained with different color filters.

In general, optimum choice of the detector spectral responses requires a priori knowledge of the spectral content of the radiation
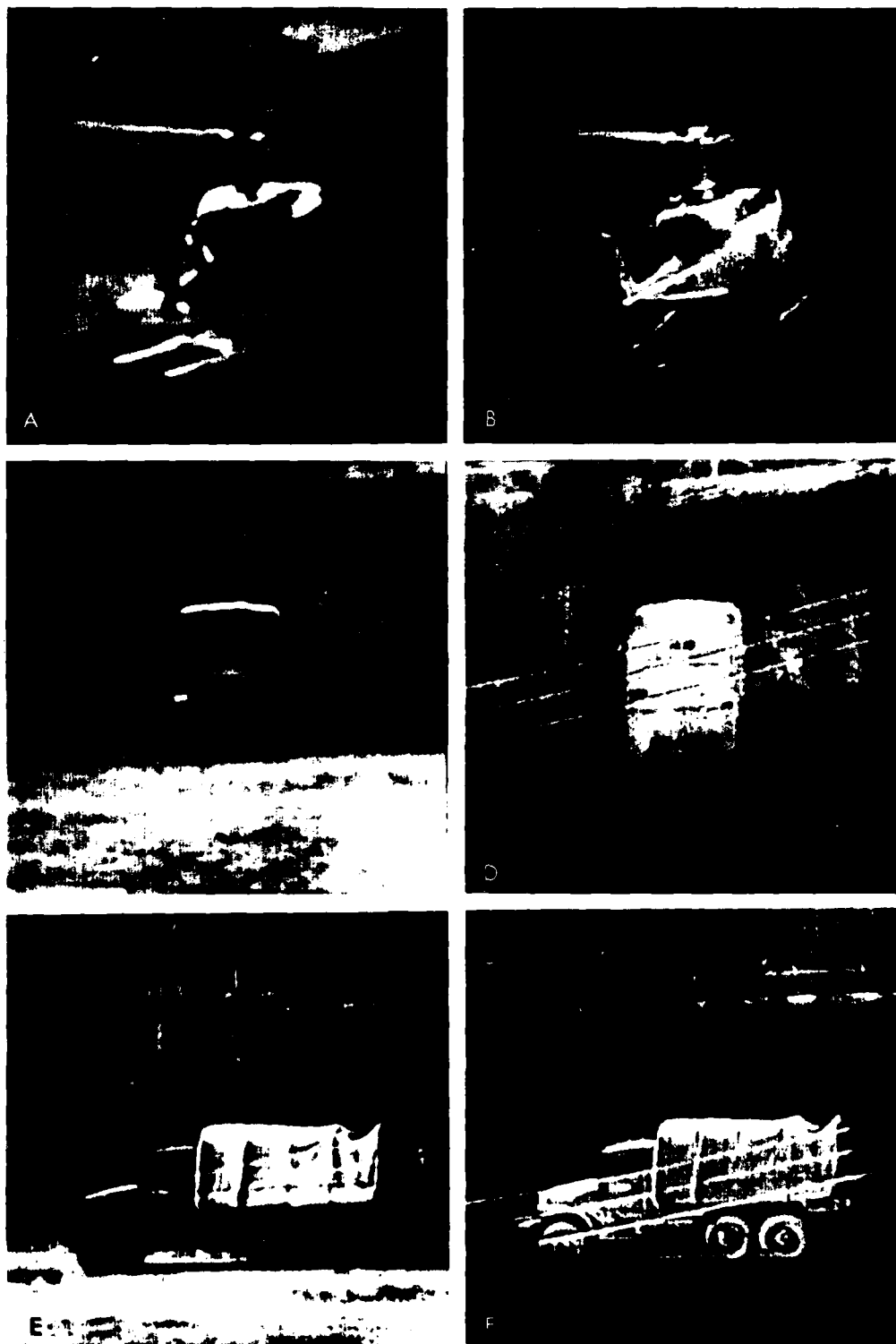
FIGURE 2 – Three original images are given in (a), (c) and (e).
Calculating the ratio of the images obtained in two different
spectral bands reduces contrast due to differences in surface
illumination and orientation, and enhances contrast due to
differences in surface material, as shown in (b), (d) and
(f).

reflected from the target and the background regions. As shown in Ref. 3, the reflectivity of "dark green paint" varies between 4% and 12% over the spectral range 0.4 to 1.8 μm. The reflectivity of green vegetation lies within the same limits over the range 0.4 to 0.65 μm (violet to scarlet), but rises rapidly to approximately 65% over the range 0.7 to 1.2 μm (red to near infrared).

We used blue-to-red and blue-to-green ratios to ensure that the targets had a higher gray level than their backgrounds in the ratio images. The 2 ratios produced similar target enhancements but different noise levels due to film granularity. The blue-to-red ratio gave a slightly lower noise level for the truck images, but the blue-to-green ratio was preferable for the helicopter one. We tried using various weighted sums and differences of the 3 color components to simulate different detector spectral responses. Interactive adjustment of these combinations allowed us to obtain better target enhancements than those shown in Fig. 2, but we made no analytic attempt to optimize the results.

The 3 ratio images given in Fig. 2 show a clear reduction in the effects of illumination and target surface orientation in comparison with the original images. Highlights on the rear wing and on the top of the helicopter, for example, appear with almost the same gray level as the shadowed back and side regions. Similarly, in the front and side views of the truck, the strongly reflecting area on the engine hood has about the same gray level as the darker front and side regions in the ratio images. This results because the metallic surfaces of the targets are coated with the same paint and have the same spectral

reflectivities. The spectral reflectivity of the canvas is also relatively uniform over its surface, and the contrast due to folds is significantly reduced in the ratio image.

Calculating the ratio did not remove all of the contrast apparently due to surface orientation and illumination effects. In the truck images, for example, the highlight on the top of the canvas covering remains. In most cases, such occurrences correspond to overexposed or underexposed regions on the film where the relationship between exposure and film density may be different for the 3 dye layers. In other cases, the remaining contrast may be due to true surface differences or to discoloration caused by weathering or by a coating of dust or dirt.

The texture of the canvas covering of the truck is different from that of the painted metallic surfaces, and this produces a large difference in gray level in the original images. It is interesting to note that because the "color" of the 2 materials is approximately the same olive drab, both appear with almost the same gray level in the ratio images. The effect of surface texture is contained in the spatial integrals in eq. 2, and these cancel in the ratio.

Other man-made objects, present in the images shown in Fig. 2, are also enhanced relative to the natural backgrounds when the ratio of the shorter wavelength image to the longer wavelength image is taken. In the side view of the truck, for example, a second set of power cables in the upper third of the image is invisible in the original, but contrasts easily with the background in the ratio. Similarly, an

aluminum-painted fence in the upper part of the same image is strongly enhanced in the ratio.

We summed 4 bands from an ERIM M7 multispectral scanner over the visible range 0.40 to 0.72 μm to produce the image shown in Fig. 3(a). Figure 3(b) gives the ratio of the image obtained in the 0.40 to 0.44 μm band to that obtained in the 0.66 to 0.84 μm band. Close inspection of the ratio image shows that most of the man-made structures have been strongly enhanced relative to the vegetation. All buildings and roadways have a high gray level that contrasts easily with the darker vegetation. For example, a nearly vertical roadway located just to the left of center is barely visible in the original image, but is clearly defined in the ratio image. Similarly, houses and roadways in the residential area in the lower right quarter of the image are strongly enhanced. Contrast caused by differences in vegetation or by shadows (the sun angle is low) is also significantly reduced.

The man-made objects are enhanced in the ratio because the vegetation typically reflects 3 times more strongly than the man-made structures in the range 0.66 to 0.84 μm, whereas their reflectivities are approximately equal in the range 0.40 to 0.44 μm. The numerous bright points in both the original and ratio images are caused by lights or other active sources and do not result from reflection of radiation. The extent to which this approach may be useful as a general method for enhancing man-made targets against natural backgrounds in visible-light imagery has yet to be determined.
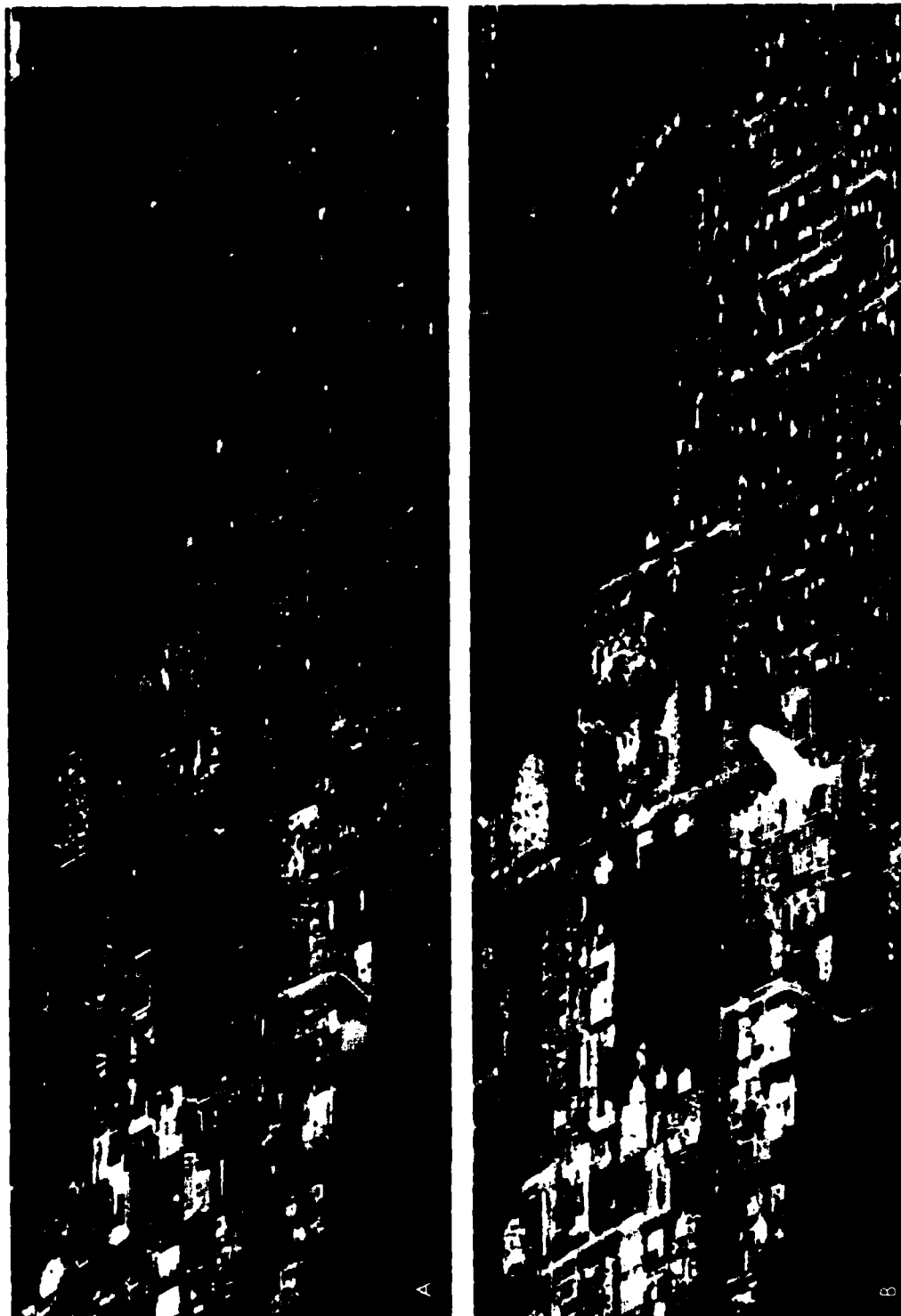
FIGURE 3 - An original aerial image is shown in (a). Dividing the corresponding image obtained in blue light by that obtained in red light enhances man-made objects relative to vegetation, as illustrated in (b).

4.0 DISCUSSION AND CONCLUSION

The objective of the present enhancement is to reduce contrast due to differences in surface illumination and orientation, since these effects are often unpredictable in practice, and to enhance contrast due to differences in surface material, the contrast of man-made objects against natural backgrounds, for example. The processing removes information, but the assumption is that the resulting image is rendered more intelligible by the attenuation of the unpredictable components.

Humans are experienced in using information obtained from changes in illumination or surface orientation, so the enhancement may be of most interest for reducing the complexity of images intended for less sophisticated machine analysis. The performance of some types of automatic target acquisition or tracking systems, for example, may be improved by applying such enhancement.

A non-updating correlation tracking system attempts to locate a previously stored reference image of a target in the input scene by correlation (Refs. 4 and 5). Good performance depends on the target illumination and orientation being the same in the reference and input scenes, but this may be difficult to guarantee in practice. If ratio images are used for the reference and input scenes, the correlation may be made less sensitive to such effects.

One type of automatic target acquisition system segments a target from its background based on the values of local features such as gray level (Refs. 6-9) or texture (Refs. 10-12). Properties of the segmented

regions, such as connectivity, area, shape, context etc., are then used to attempt to locate or classify the targets of interest (Ref. 13). In the original target images shown in Fig. 2, the targets cannot be segmented from the background regions by setting a single gray-level threshold level. Some areas of the targets are darker than the background, whereas others are lighter than it. In the ratio images, however, most areas of the targets are clearly higher than the background region in gray level, and segmentation using the color-ratio feature would more closely preserve the shape of the target. We plan to do further work to evaluate, by simulation, the possible uses of this technique with specific target acquisition and tracking algorithms.

Other target analysis operations, such as those based on extracting a characteristic target signature (e.g. as obtained with the 2-dimensional power spectrum, Ref. 14), may give better results if the unpredictable illumination and orientation effects are first removed from the target image. There may also be applications in the general areas of pattern recognition and image understanding (Ref. 15). In particular, the information obtained from the ratio image could be useful for detecting homogeneous regions or objects that differ in gray level because of differences in surface illumination or orientation.

Enhancement of image displays intended for human interpretation is another possible area of military interest. The various bands available from a multispectral imaging system, for example, could be suitably combined to synthesize the 2 detector responses required to enhance the contrast of a particular type of target against a specific type of background. However, the images obtained in all spectral bands

must be formed by reflection of radiation. An image formed by the emission of infrared radiation in the 9-13 μm band, for example, could not be used.

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"Rehaussement d'images par le rapport des couleurs"
par J. F. Boulter

Dans une image produite par la réflexion de la radiation, le contraste résultant des différents types de surface est souvent plus important que celui causé par des différences de l'illumination ou de l'orientation des surfaces. Ce contraste peut être difficile à prévoir, en pratique. On démontre que, dans plusieurs cas, le contraste produit par les différences de l'illumination ou de l'orientation peut être réduit ou éliminé si on divise une image obtenue dans une bande spectrale par celle provenant d'une bande spectrale différente. On applique cette technique pour rehausser des images des véhicules militaires enregistrées sur un film en couleur de même que celles d'objets faits par l'homme par rapport à la végétation sur une image obtenue avec balayeur multispectral. (NC)

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"Image Enhancement by Spectral Ratioing"
by J. F. Boulter

In a reflectivity image, contrast produced by differences in surface material is often of more interest than that produced by differences in surface orientation or illumination. The latter factors may be difficult to predict or to allow for in practice. We show that, in certain cases, contrast caused by differences in surface orientation and illumination may be reduced or eliminated by dividing obtained in one spectral band by one obtained in a different spectral band. We illustrate this technique by enhancing the images of military vehicles recorded on color film, and by enhancing man-made objects in an aerial multispectral scanner image relative to vegetation. (U)